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PATENT APPLICATION SERIAL NO. ____________________

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07/23/03

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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request f r filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53 (c).

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60/489429

INVENTOR(S)		
Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
Ingmar	GRAESSLIN	Bonningstedt, DE
Holger	EGGERS	Kaltenkirchen, DE

☐ *Additional inventors are being named on the _____ separately numbered sheets attached hereto*

TITLE OF THE INVENTION (280 characters max)

EFFICIENT MAPPING OF RECONSTRUCTION ALGORITHMS FOR MAGNETIC RESONANCE IMAGING ONTO A RECONFIGURABLE RECONSTRUCTION SYSTEM

CORRESPONDENCE ADDRESS

Direct all correspondence to:

☐ Customer Number [ ] → *Place Customer Number Bar Code Label here*

OR *Type Customer Number here*

☒ Firm or Individual Name	THOMAS E KOCOVSKY, JR				
Address	FAY, SHARPE, FAGAN, MINNICH & McKEE, LLP				
Address	1100 SUPERIOR AVENUE, SEVENTH FLOOR				
City	CLEVELAND	State	OH	ZIP	44114
Country	US	Telephone	216/861-5582	Fax	216/241-1666

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☒ Drawing(s) *Number of Sheets* 13 ☐ Other (specify)

☒ Application Data Sheet. See 37 CFR 1.76

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT (*check one*)

☐ Applicant claims small entity status. See 37 CFR 1.27.

☒ A check or money order is enclosed to cover the filing fees

☐ The Commissioner is hereby authorized to charge filing fees or credit any overpayment to Deposit Account Number: 06-0308

☐ Payment by credit card. Form PTO-2038 is attached.

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The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

☐ No.

☐ Yes, the name of the U.S. Government agency and the Government contract number are: _____.

Respectfully submitted,

SIGNATURE Thomas E. Kocovsky

Date 07/23/2003

TYPED or PRINTED NAME THOMAS E. KOCOVSKY, JR.

REGISTRATION NO. *(if appropriate)* 28,383

TELEPHONE 216 861-5582

Docket Number: PHUS030240USP

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Attorney's Docket No. PHUS030240USP (202839)

APPLICATION DATA SHEET

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Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Inventor Information

Inventor One Given Name::	Ingmar
Family Name::	GRAESSLIN
City::	Bonningstedt
Country::	DE
Inventor Two Given Name::	Holger
Family Name::	EGGERS
City::	Kaltenkirchen
Country::	DE

Correspondence Information

Name Line One::	Thomas E. Kocovsky, Esq.
Name Line Two::	FAY, SHARPE, FAGAN,
Name Line Three::	MINNICH & McKEE, LLP
Address Line One::	1100 Superior Avenue, Seventh Floor
City::	Cleveland
State or Province::	OH
Postal or Zip Code::	44114-2518
Telephone One::	(216) 861-5582
Fax::	(216) 241-1666
Electronic Mail::	TKocovsky@faysharpe.com

Representative Information

Registration Number::	28,383

Application Information

Title Line One::	EFFICIENT MAPPING OF RECONSTRUCTION
Title Line Two::	ALGORITHMS FOR MAGNETIC RESONANCE
Title Line Three::	IMAGING ONTO A RECONFIGURABLE
Title Line Four::	RECONSTRUCTION SYSTEM
Total Drawing Sheets::	13
Application Type::	Provisional
Docket Number::	PHUS030240USP (202839)

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Hilary M. McNulty
By: Hilary M. McNULTY

EFFICIENT MAPPING OF RECONSTRUCTION ALGORITHMS FOR MAGNETIC RESONANCE IMAGING ONTO A RECONFIGURABLE RECONSTRUCTION SYSTEM

Background of the Invention

The present invention relates to diagnostic medical imaging. It finds particular application in conjunction with the reconstruction of magnetic resonance images and will be described with particular reference thereto.

Heretofore, magnetic resonance imaging scanners have included a main magnet, typically superconducting, which generates a temporally constant magnetic field B_0 through an examination region. A radio frequency coil, such as a whole-body coil, and a transmitter tuned to the resonance frequency of the dipoles to be imaged in the B_0 field have often been used to excite and manipulate these dipoles. Spatial information has been encoded by driving the gradient coils with currents to create magnetic field gradients in addition to the B_0 field across the examination region in various directions. Magnetic resonance signals have been acquired by the same coil, demodulated, filtered and sampled by an RF receiver and finally reconstructed into an image on some dedicated or general-purpose hardware.

Rather than using the same coil to transmit and receive RF pulses, the use of surface or local receive coils has become more and more common recently. These receive coils are often arranged in arrays, in which each coil element produces its own output. Instead of combining the outputs of the coil elements in the analog domain, it has proven advantageous to reconstruct the output from individual coil elements separately. Therefore, each coil element is typically connected with its own RF receiver.

While current scanners claim to have a few receive channels with independent RF receivers, they still have only a single reconstruction unit. The processing of the data from each of the RF receivers is interleaved in time in the

reconstruction unit, although it may be performed in parallel to reduce reconstruction times.

Simply multiplying the reconstruction units gives rise to the problem of how to map the processing efficiently onto the individual units. A fixed allocation of reconstruction units to receive channels, for example, makes only poor use of available hardware since varying numbers of coil elements might be employed in practice. Moreover, the complexity of the reconstruction software generally increases considerably to divide the processing suitably among the reconstruction units.

The present invention provides an improved imaging apparatus and an improved method, which overcome the above-referenced problems and others.

Summary of the Invention

In accordance with one aspect of the present invention, an MRI system is disclosed. A means creates and transmits RF pulses into an examination region to excite and manipulate a spin system to be imaged. A means picks up an MR signal emitted from the examination region. A means demodulates the MR signal and converts the demodulated MR signal into digital data. A means, including a plurality of reconfigurable processing units with dynamically reconfigurable connections, reconstructs the digital data into images.

In accordance with another aspect of the present invention, a method for processing an MR signal is disclosed. RF pulses are created and transmitted into an examination region to excite and manipulate a spin system to be imaged. The MR signal, emitted from the examination region, is picked up. The picked up MR signal is demodulated and converted into digital data. The digital data is reconstructed into images via a plurality of processing units with dynamically reconfigurable connections.

Advantages of the present invention reside, inter alia, in an increased reconstruction speed due to a more efficient utilization of hardware resources, and simpler reconstruction software architecture due to a single general strategy for mapping processing tasks to hardware resources.

Brief Description of the Drawings

The invention may take form in various components and arrangements of components, and in various steps and arrangements of steps. The drawings are only for purposes of illustrating the preferred embodiments and are not be construed as limiting the invention.

FIGURE 1 is a diagrammatic illustration of a magnetic resonance imaging system in accordance with the present invention;

FIGURE 2 is a diagrammatic illustration of a reconfigurable reconstruction system in accordance with the present invention;

FIGURE 3 is a diagrammatic illustration of a possible distribution of processing tasks over four pipeline stages in accordance with the present invention;

FIGURE 4 is a diagrammatic illustration of a possible timing for executing an iterative reconstruction on four processing units per channel in accordance with the present invention;

FIGURES 5A-B depict two alternative techniques for combining images from individual processing channels to create a final combined image in accordance with the present invention;

FIGURE 6A is a diagrammatic illustration of a reconfigurable reconstruction system utilizing six processing channels with one pipeline stage each in accordance with the present invention;

FIGURE 6B is a diagrammatic illustration of a reconfigurable reconstruction system utilizing three processing channels with two pipeline stages in accordance with the present invention;

FIGURE 6C is a diagrammatic illustration of a reconfigurable reconstruction system utilizing two processing channels with three pipeline stages each in accordance with the present invention;

FIGURES 7A-C are diagrammatic illustrations of a reconfigurable reconstruction system built up of boards comprising six embedded processing units each that supports different numbers of processing channels and pipeline stages while utilizing the same total number of processing units, in accordance with the present invention;

FIGURE 8 is a diagrammatic illustration of a reconfigurable reconstruction system built up of a general-purpose hardware, including personal computers or workstations as processing units and a switch as an interconnection.

Detailed Description of the Preferred Embodiments

With reference to FIGURE 1, a magnetic resonance (MR) imaging scanner **10** includes a preferably superconducting main magnet **12**, which includes a solenoid coil in the illustrated embodiment. The main magnet **12** generates a spatially and temporally constant magnetic field B_0 through an examination region **14** in a bore **16** of the magnet **12** .

Magnetic field gradients across the examination region **14** are generated by gradient coils **18** to spatially encode an MR signal, to spoil the magnetization, and the like. In the preferred embodiment, the gradient coils **18** produce gradients in three orthogonal directions, including a longitudinal or z-direction and transverse or x- and y-directions.

A whole-body coil **20**, preferably a birdcage coil, transmits radiofrequency (RF) signals for exciting and manipulating a spin system to be imaged and may also receive the MR signal.

A plurality of local RF coils **22** is disposed in the bore **16**. The local coils **22** include in the illustrated embodiment a phased-array coil **24**, which includes seven coil elements. Optionally, the phased-array coil may be built into a patient support **26**. In addition, a surface coil array **28** is disposed in the bore **16**. It may include a plurality of surface coils, coils which view different regions of the subject, coils which view a common region of the subject, but have different reception properties, and the like.

To perform measurements, a subject is placed in the magnet's bore **16** with the region of interest in the examination region at or near the magnet's isocenter. A sequence controller **30** controls the gradient amplifiers **32**, which drive the gradient coils to create gradient magnetic fields with appropriate strength, orientation and timing. The sequence controller **30** also controls the radiofrequency transmitter **34** which, with the help of the whole-body coil **20**, sends radiofrequency pulses into the examination region **14** to excite and manipulate the spin system to be imaged.

Magnetic resonance signals are induced in selected receive coils in the examination region **14**. Each of n elements of the local coil arrays **22** is connected with one of n RF receivers **36_1, ..., 36_n**. The whole-body coil **20** is also preferably connected to one additional RF receiver.

The reconfigurable reconstruction system **40** supports up to n independent processing channels **42_1, ..., 42_n**, with each of these channels connected to one of the RF receivers **36_1, ..., 36_n**. The images reconstructed separately by the processing channels are finally combined by the combining unit **44**. The combined images (and optionally the uncombined images) are sent to the host computer **50** for storage and viewing. The host computer **50**, preferably a personal computer or workstation, includes a display and a user interface connected with the sequence controller **30**, which allows the operator to select among a variety of sequences and imaging parameters.

With continuing reference to FIGURE 1 and further reference to FIGURE 2, the data provided by coils **20, 22, 28** are sent via the RF receivers or receive channels **36_1, ..., 36_n** to corresponding individual channels of a plurality of processing channels **42_1, 42_2, ..., 42_n**. The data are processed by a plurality of processing or reconstruction units **52**, arranged in the pipeline stages **54_1, 54_2, ... 54_m**. The allocation of processing or reconstruction units **52** to processing channels and pipeline stages is performed dynamically on a per scan basis. Moreover, the number of processing channels is adapted to the number of receive channels actually in use, i.e. it is chosen to be a multiple or a factor of the number of active receive channels, or to be the same. The images reconstructed separately by the processing channels **42_1, 42_2, ..., 42_n** are sent to the combining unit **44**, where the images are combined.

With reference to FIGURE 3, one of the processing channels of the reconstruction system is shown in more detail. The reconstruction is performed using four pipeline stages **54_1, 54_2, 54_3**, and **54_4**. The first pipeline stage **54_1** operates on the data in k-space. It performs, for instance, a sampling density compensation or a regridding. The intermediate pipeline stages **54_2** and **54_3** transform the data from k-space to spatial (or image) domain. The use of two pipeline stages permits, in this case, to separate the two-dimensional Fourier transform required in two-dimensional imaging into two subsequent one-dimensional Fourier transforms, allocating one of

them to each pipeline stage. The final pipeline stage 54_4 operates on the data in the image domain. It performs, for instance, a roll-off correction or weighting. Alternatively, the images from the individual processing channels are also partly or completely combined in the final pipeline stage to drastically reduce the required bandwidth to the combining unit. In case of an iterative reconstruction, for which a variety of algorithms are known, these processing steps make up the forward processing. Keeping the same mapping of processing tasks to the pipeline stages, the backward processing can be implemented similarly by sending the data in reverse direction from the last to the first pipeline stage. In addition, some further processing in the spatial domain has to be implemented in the last pipeline stage. It includes the core of the iterative reconstruction, such as the conjugate gradient or the generalized minimum residual method, but without the matrix-vector multiplication, and a redistribution of the final combined image to all processing or reconstruction units allocated to the last pipeline stage before the beginning of a new iteration.

FIGURE 4 shows a possible timing for an iterative reconstruction executed on the four pipeline stages 54_1, 54_2, 54_3, and 54_4 of FIGURE 3. P_xy denotes the processing of image x in iteration y. In the initial iteration, an image A is manipulated in pipeline stages 54_1, 54_2, 54_3, and 54_4 using the forward processing. The images B, C, and D enter pipeline stage 54_1 at suitable later times. When the first image A reaches pipeline stage 54_4, pipeline stage 54_1 has processed images B, C, and D in the initial iteration. Then, the backward processing starts with the image A in the first iteration on pipeline stage 54_4. Preferably, a first chain of processors is dedicated to the forward processing and a second chain of processors is dedicated to the backward processing, although the forward and backward processing can also be executed, even simultaneously, on the same processors.

In FIGURE 5A and 5B, exemplary techniques for combining images reconstructed separately by the processing channels are shown. The combination is performed by the processing or reconstruction units allocated to the last pipeline stage 54_m, which have the capability of exchanging data with each other.

In FIGURE 5A, the image from channel 42_1 is combined with the image from channel 42_2, producing an intermediate combined image, which is sent to the adjacent channel 42_3 to be further combined with the image from this channel. At the same time, the image from channel 42_n is combined with the image from

channel 42_{n-1}, producing an intermediate combined image, which is sent to the adjacent channel 42_{n-2} to be further combined with the image from this channel. After the final combined image from all channels $42_1, 42_2, \ldots, 42_n$ has been obtained after n/2 steps, it is sent to the combining unit **44** for further processing.

In FIGURE 5B, the images from channels 42_1 and 42_2, 42_3 and 42_4, …, 42_{n-1} and 42_n are combined in parallel. After the final combined image from all channels $42_1, 42_2, \ldots, 42_n$ has been obtained, it is sent to the combining unit **44** for further processing. Alternatively, the combination process may be stopped earlier and all remaining intermediate combined images may be sent to the combining unit **44** for further processing.

FIGURES 6A-C illustrate exemplary implementations of the present invention utilizing six processing or reconstruction units $52_1, 52_2, \ldots, 52_6$. In FIGURE 7, six processing or reconstruction units $52_1, 52_2, \ldots, 52_6$ are configured to process six channels $42_1, 42_2, \ldots, 42_6$, with a single pipeline stage 54_1 each. The data from six coil elements are sent to six corresponding processing channels. The six images from each of the processing channels are summed up in the combining unit **44**.

In FIGURE 6B, six processing or reconstruction units $52_1, 52_2, \ldots, 52_6$ are configured to process three channels 42_1, 42_2, and 42_3 with two pipeline stages 54_1, 54_2 each. The data from three coil elements are sent to three corresponding processing channels. The three images from each of the processing channels are summed up in the combining unit **44**.

In FIGURE 6C, six processing or reconstruction units $52_1, 52_2, \ldots, 52_6$ are configured to process two channels 42_1 and 42_2 with three pipeline stages 54_1, 54_2 and 54_3 each. The data from two coil elements are sent to two corresponding processing channels. The two images from each of the processing channels are summed up in the combining unit **44**.

FIGURES 7A-C and 8 show two alternative implementations of the interconnections between the six processing or reconstruction units $52_1, 52_2, \ldots, 52_6$ of FIGURES 6A-C using a switch **60** or other hardware with similar functionality. The interconnections can be configured to realize the network topologies of FIGURES 6A-C. Although six processing units are shown by way of example, any number of processors could be used.

In FIGURE 7A, a crossbar switch **60** is used to connect the six embedded processors **52_1, 52_2, ..., 52_6** of FIGURE 6A, which allows a static configuration of the connections **56** in hardware on a per scan basis. Each processor receives input data separately via the inputs I_1 through I_6. The processors **52_1, 52_2, ..., 52_6** exchange images with each other via the crossbar **60**. After completion of reconstruction, each processor sends an image via the outputs O_1 through O_6 to the combining unit **44**. Alternatively, the image combination is performed partly or entirely on the processors themselves, as discussed above.

In FIGURE 7B, a crossbar switch **60** is used to connect the six embedded processors **52_1, 52_2, ..., 52_6** as shown in FIGURE 6B. The processors **52_1, 52_3**, and **52_5** are allocated to the pipeline stage **54_1** of channels **42_1, 42_2**, and **42_3**. The processors **52_1, 52_3**, and **52_5** receive input data via the inputs I_1 through I_3. The processors **52_2, 52_4**, and **52_6** are allocated to the pipeline stage **54_2** of channels **42_1, 42_2**, and **42_3**. The processors **52_2, 52_4**, and **52_6** exchange images with each other via the crossbar **60**. After completion of reconstruction, the processors **52_2, 52_4**, and **52_6** send images via the outputs O_1 through O_3 to the combining unit **44**.

In FIGURE 7C, a crossbar switch **60** is used to connect the six embedded processors **52_1, 52_2, ..., 52_6** as shown in FIGURE 6C. The processors **52_1** and **52_4** are allocated to the pipeline stage **54_1** of channels **42_1** and **42_2**. The processors **52_1** and **52_4** receive input data via the inputs I_1 and I_2. The processors **52_3** and **52_6** are allocated to the pipeline stage **54_3** of channels **42_1** and **42_2**. The processors **52_3** and **52_6** exchange images with each other via the crossbar **60**. After completion of the reconstruction, the processors **52_3** and **52_6** send images via the outputs O_1 and O_2 to the combining unit **44**.

In FIGURE 8, a switched fabric switch **60** is used to connect the six personal computers or workstations **52_1, 52_2, ..., 52_6**, each serving as one processing or reconstruction unit. The switch **60** permits a dynamic configuration of the connections **56** in software for each packet of data.

Thus, the systems shown in FIG. 7A-C and 8 can be configured for a first scan to have six processing channels with one pipeline stage each as per FIG. 7A; for a second scan to have three processing channels with two pipeline stages each as per FIG. 7B; and for a third scan to have two processing channels with three pipeline stages each as per FIG. 7C. Further, each processing or reconstruction unit

need not be dedicated to a specific channel. Rather, one or more of the processing or reconstruction units can be shared between two or more channels.

The invention has been described with reference to the preferred embodiments. Modifications and alterations may occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be constructed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

Having thus described the preferred embodiments, the invention is now claimed to be:

1. An MRI system comprising:

a means **(34)** for creating and transmitting RF pulses into an examination region **(14)** to excite and manipulate a spin system to be imaged;

a means **(20, 24, 28)** for picking up an MR signal emitted from the examination region **(14)**;

a means **(36)** for demodulating the MR signal and converting the demodulated MR signal into digital data; and

a means **(40)** for reconstructing images from the digital data, which includes:

a plurality of processing units **(52)**, which include dynamically reconfigurable connections **(56)**.

2. The MRI system as set forth in claim 1, wherein the plurality of processing units **(52)** includes embedded processors.

3. The MRI system as set forth in claim 1, wherein the plurality of processing units **(52)** includes one of personal computers and workstations.

4. The MRI system as set forth in claim 1, wherein the processing units **(52)** are dynamically reconfigured utilizing a switched fabric, a crossbar **(60)** or the like.

5. The MRI system as set forth in claim 1, wherein the means **(20, 24, 28)** for picking up the MR signal includes a plurality of coil elements and the means **(36)** for demodulating and converting the MR signal includes a plurality of RF receivers **(36_1, 36_2, ..., 36_n)**, each operatively connected to an associated coil element, and further including:

a means (60) for interconnecting the processing units (52) to arrange the processing units (52) into a plurality of independent parallel processing channels (42_1, 42_2, ..., 42_n), each channel being operatively connected with one or more RF receivers (36_1, 36_2, ..., 36_n).

6. The MRI system as set forth in claim 5, wherein each of the independent parallel processing channels (42_1, 42_2, ..., 42_n) further include:

one or more pipeline stages (54_1, 54_2, ..., 54_m).

7. The MRI system as set forth in claim 6, wherein each of the independent parallel processing channels (42_1, 42_2, ..., 42_n) further include:

a first pipeline stage (54_1) to operate on the digital data in k-space;

one or more intermediate pipeline stages (54_2, 54_3) to transform the digital data from k-space to an image domain; and

a final pipeline stage (54_4) to operate on the digital data in the image domain.

8. The MRI system as set forth in claim 6, further including:

a combining unit (44), operatively connected to the processing units (52) allocated to a final pipeline stage (54_m), to manipulate outputs of each channel.

9. The MRI system as set forth in claim 8, wherein the combining unit (44) weights the output of each channel and sums the weighted outputs.

10. The MRI system as set forth in claim 8, wherein an exchange of the data generated by the independent processing channels (42_1, 42_2, ..., 42_n) is restricted to an image domain and further includes:

one of the exchange of the data via the processing units (52) allocated to the final pipeline stage (54_m) and via the combining unit (44).

11. A method for processing an MR signal comprising:

creating and transmitting RF pulses into an examination region (14) to excite and manipulate a spin system to be imaged;

picking up the MR signal emitted from the examination region **(14)**;

demodulating the picked up MR signal and converting the demodulated MR signal into digital data; and

reconstructing images from the digital data via a plurality of processing units **(52)**, which include dynamically reconfigurable connections **(56)**.

12. The method as set forth in claim 11, further including:

dynamically reconfiguring the processing units connections **(56)** to allocate the processing units **(52)** to processing channels **(42_1, 42_2, ..., 42_n)** and pipeline stages **(54_1, 54_2, ..., 54_m)** on a per scan basis.

13. The method as set forth in claim 12, further including:

dynamically allotting the processing channels **(42_1, 42_2, ..., 42_n)** to RF receivers **(36_1, ..., 36_n)** in use.

14. The method as set forth in claim 11, further including:

interconnecting the processing units **(52)** to arrange the processing units **(52)** into a plurality of independent parallel processing channels **(42_1, 42_2, ..., 42_n)**, each channel being operatively connected with one or more RF receivers **(36_1, 36_2, ..., 36_n)**; and

reconstructing the images from the digital data via independent processing in each independent processing channel.

15. The method as set forth in claim 14, wherein the processing units **(52)** in each independent parallel processing channel are arranged into a plurality of pipeline stages **(54_1, 54_2, ..., 54_m)**.

16. The method as set forth in claim 15, further including:

weighing an output of each processing channel; and

one of partial and complete combining of the weighed outputs.

17. The method as set forth in claim 16, wherein the combining is performed in a final pipeline stage **(54_m)** and includes:

combining an image from a first channel **(42_1)** with an image from an adjacent channel **(42_2)** to form a first intermediate combined image, and combining an image from a channel n **(42_n)** with an image from an adjacent channel **(42_{n-1})** to form a second intermediate combined image; and

combining each intermediate combined image with an image from another channel to generate new intermediate combined images until images from all channels have been combined into a resultant combined image.

18. The method as set forth in claim 17, further including:

distributing the resultant combined image to the processing units **(52)** allocated to the final pipeline stage **(54_m)** by consecutively forwarding the resultant combined image from the middle channel **($42_{n/2}$)** in direction of the last channel **(42_n)** and simultaneously forwarding the resultant combined image in opposite directions from the middle channel **($42_{n/2}$)** in direction of the last channel **(42_n)** via adjacent processing units.

19. The method as set forth in claim 16, wherein the combining is performed in a final pipeline stage **(54_m)** and includes:

combining images from pairs of processing channels into intermediate combined images; and

combining pairs of the intermediate combined images until images from all channels have been combined into a resultant combined image.

20. The method as set forth in claim 19, further including:

distributing the resultant combined image to the processing units **(52)** allocated to the final pipeline stage **(54_m)** by consecutively forwarding the resultant combined image from the middle channel **($42_{n/2}$)** to the last channel **(42_n)** and simultaneously forwarding the resultant combined image in opposite directions from the middle channel **($42_{n/2}$)** to the last channel **(42_n)** via adjacent processing units.

21. The method as set forth in claim 14, further including:

mapping a forward processing of iterative reconstruction algorithms to the pipeline stages **(54_1, 54_2, ..., 54_m)**;

mapping a backward processing of the iterative reconstruction algorithms to the pipeline stages (54_m, 54_{m-1}, ..., 54_1); and

simultaneously performing the forward and backward processing of different data sets, such that:

a first pipeline stage (54_1) operates on the digital data in k-space, and

a final pipeline stage (54_m) operates on the digital data in an image domain.

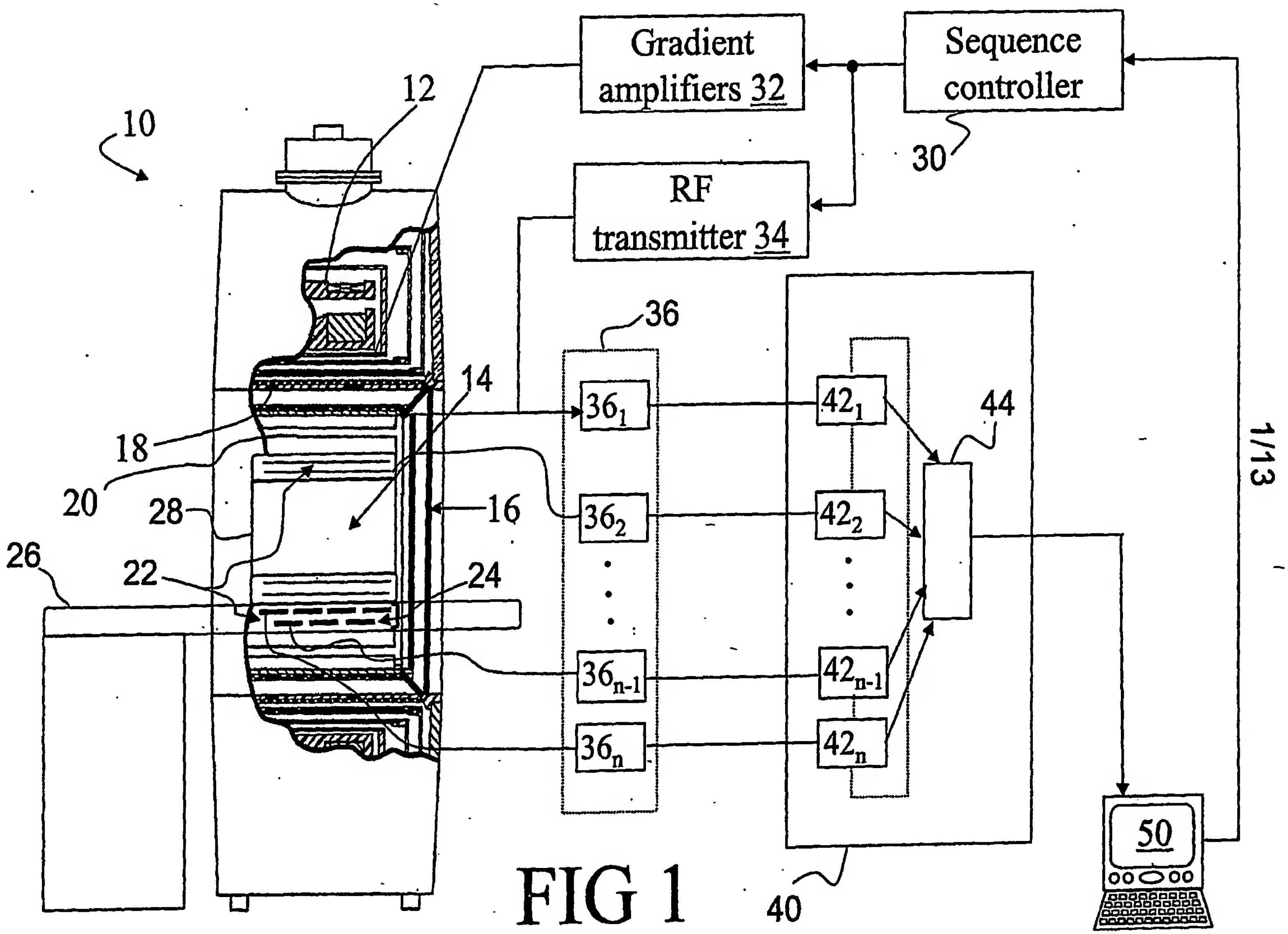
22. The method as set forth in claim 21, further including:

utilizing two separate independent parallel processing channels for the forward and backward processing of iterative reconstruction algorithms.

EFFICIENT MAPPING OF RECONSTRUCTION ALGORITHMS FOR MAGNETIC RESONANCE IMAGING ONTO A RECONFIGURABLE RECONSTRUCTION SYSTEM

Abstract of the Disclosure

A magnetic resonance (MR) system **(10)** includes radiofrequency (RF) transmitters **(34)** which send RF pulses into an examination region **(14)** to excite a spin system to be imaged. Coil elements **(20, 24, 28)** pick up an MR signal, which is demodulated and converted into digital data by RF receivers **(36)**. A plurality of independent parallel processing channels **(42_1, 42_2, ..., 42_n)** is operatively connected to the RF receivers to reconstruct images from the digital data. The parallel processing channels **(42_1, 42_2, ..., 42_n)** include one or more pipeline stages **(54_1, 54_2, ..., 54_m)**. Processing channels and pipeline stages include a plurality of processing or reconstruction units **(52)**. Processing tasks are dynamically allocated to these processing or reconstruction units on a per scan basis using a single general strategy for mapping processing tasks to hardware resources. The connections **(56)** between the processing or reconstruction units **(52)** are reconfigured using a switching means **(60)**. In this manner, different numbers of coil elements **(20, 24, 28)** can be connected with matching numbers of processing channels **(42_1, 42_2, ..., 42_n)** to exploit available processing resources optimally.



Gradient amplifiers 32
Sequence controller
30
RF transmitter 34
10
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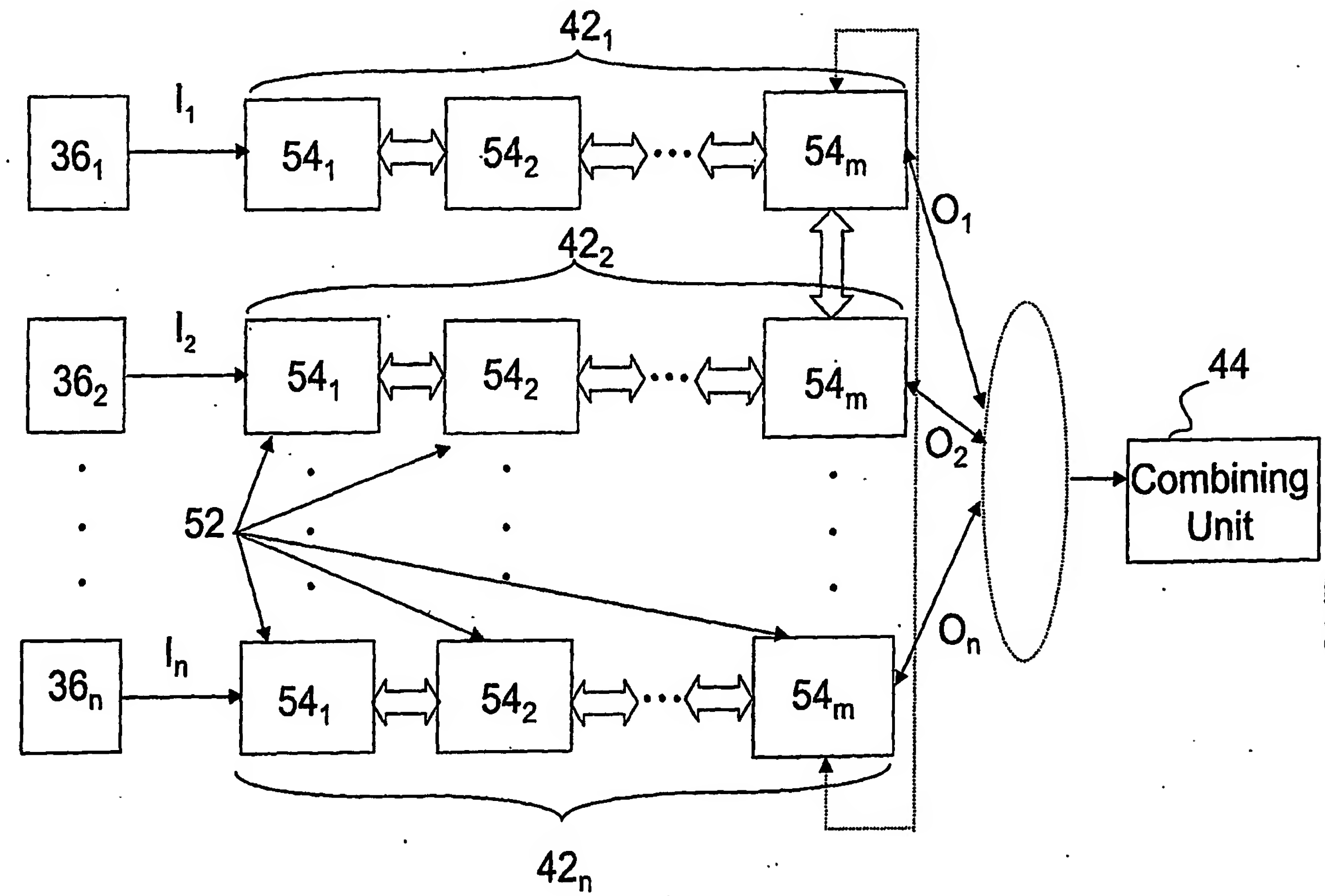
28
36
36_1
36_2
36_{n-1}
36_n
42_1
42_2
42_{n-1}
42_n
44
40
50

FIG 1



36_1
36_2
36_n
I_1
I_2
I_n
42_1
42_2
42_n
54_1
54_2
54_m
52
O_1
O_2
O_n
44
Combining Unit

FIG 2

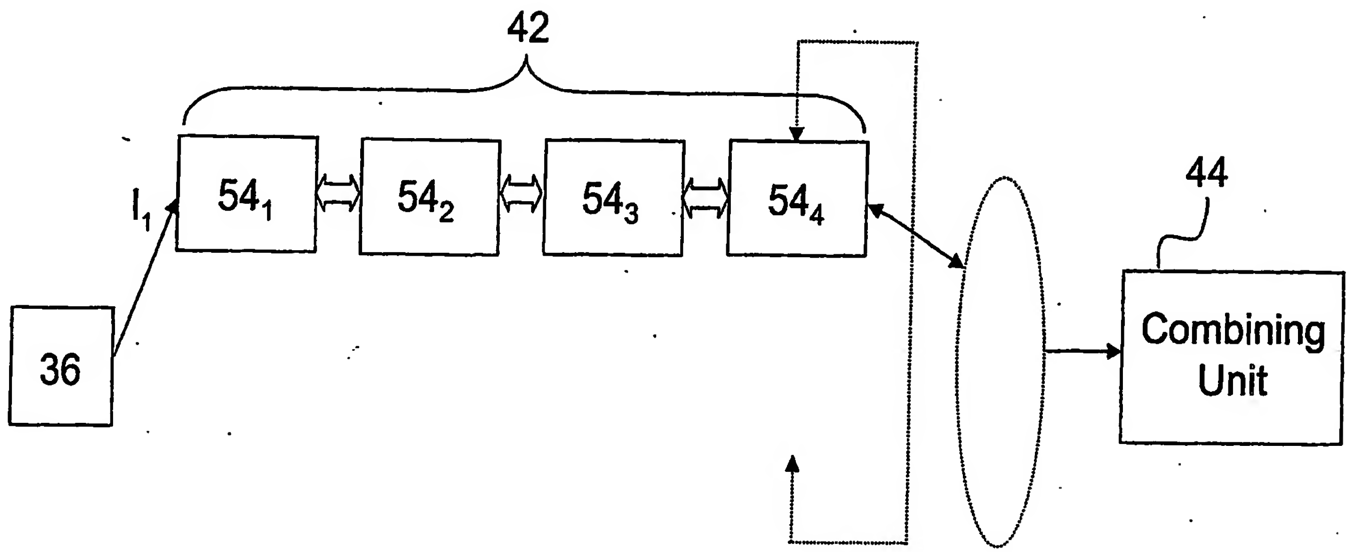
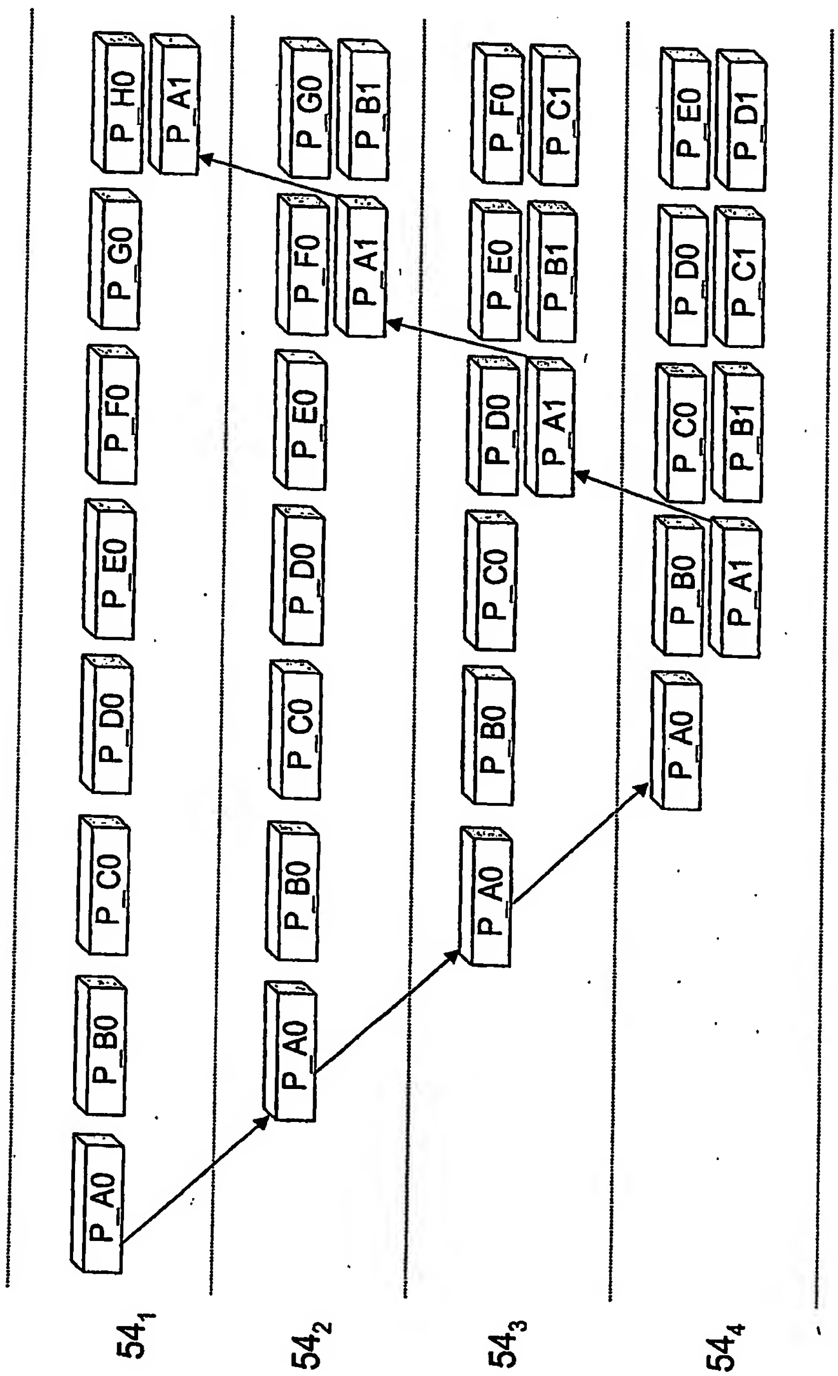


FIG 3



54_1
P_A0
P_B0
P_C0
P_D0
P_E0
P_F0
P_G0
P_H0
P_A1
54_2
P_A0
P_B0
P_C0
P_D0
P_E0
P_F0
P_A1
P_G0
P_B1
54_3
P_A0
P_B0
P_C0
P_D0
P_A1
P_E0
P_B1
P_F0
P_C1
54_4
P_A0
P_B0
P_A1
P_C0
P_B1
P_D0
P_C1
P_E0
P_D1

FIG 4

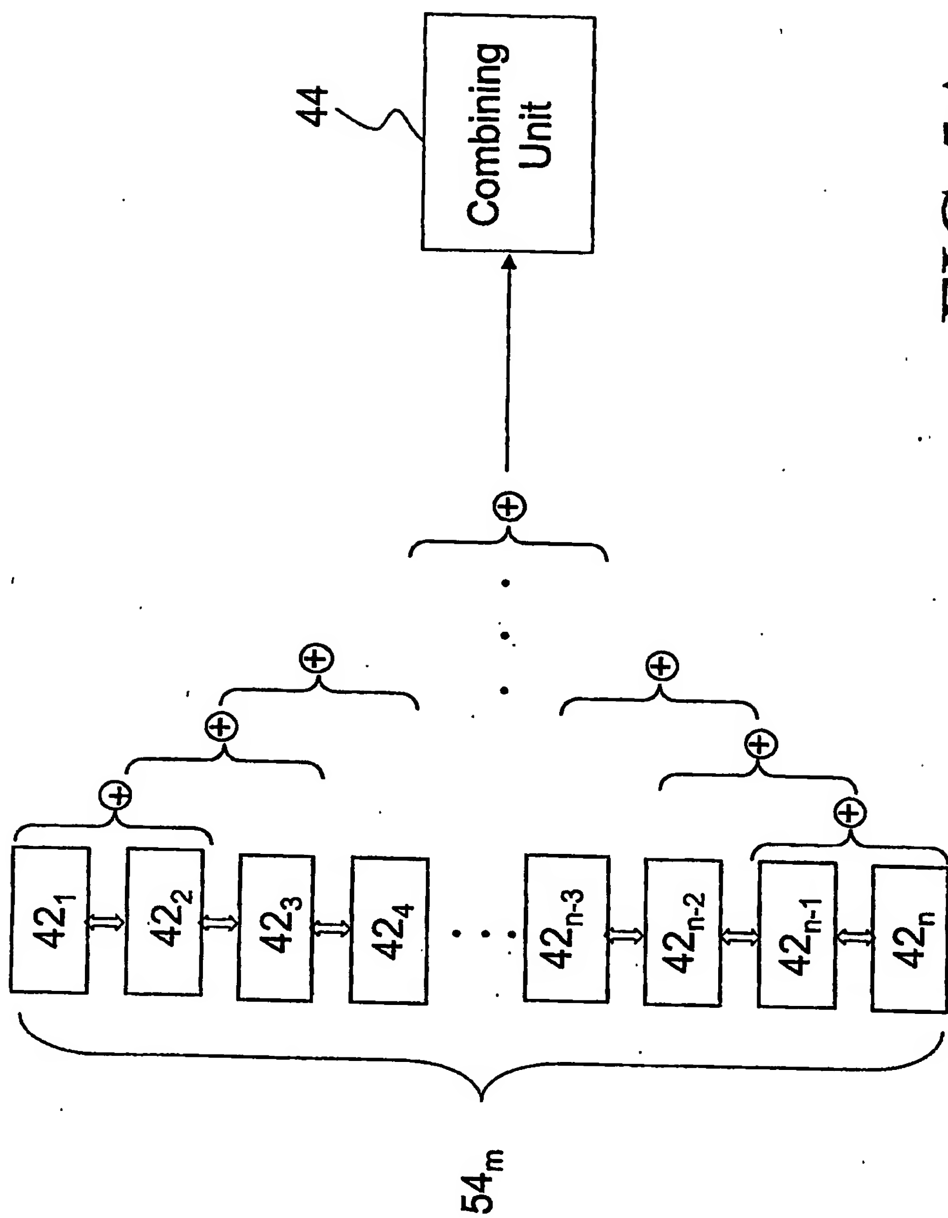


FIG 5A

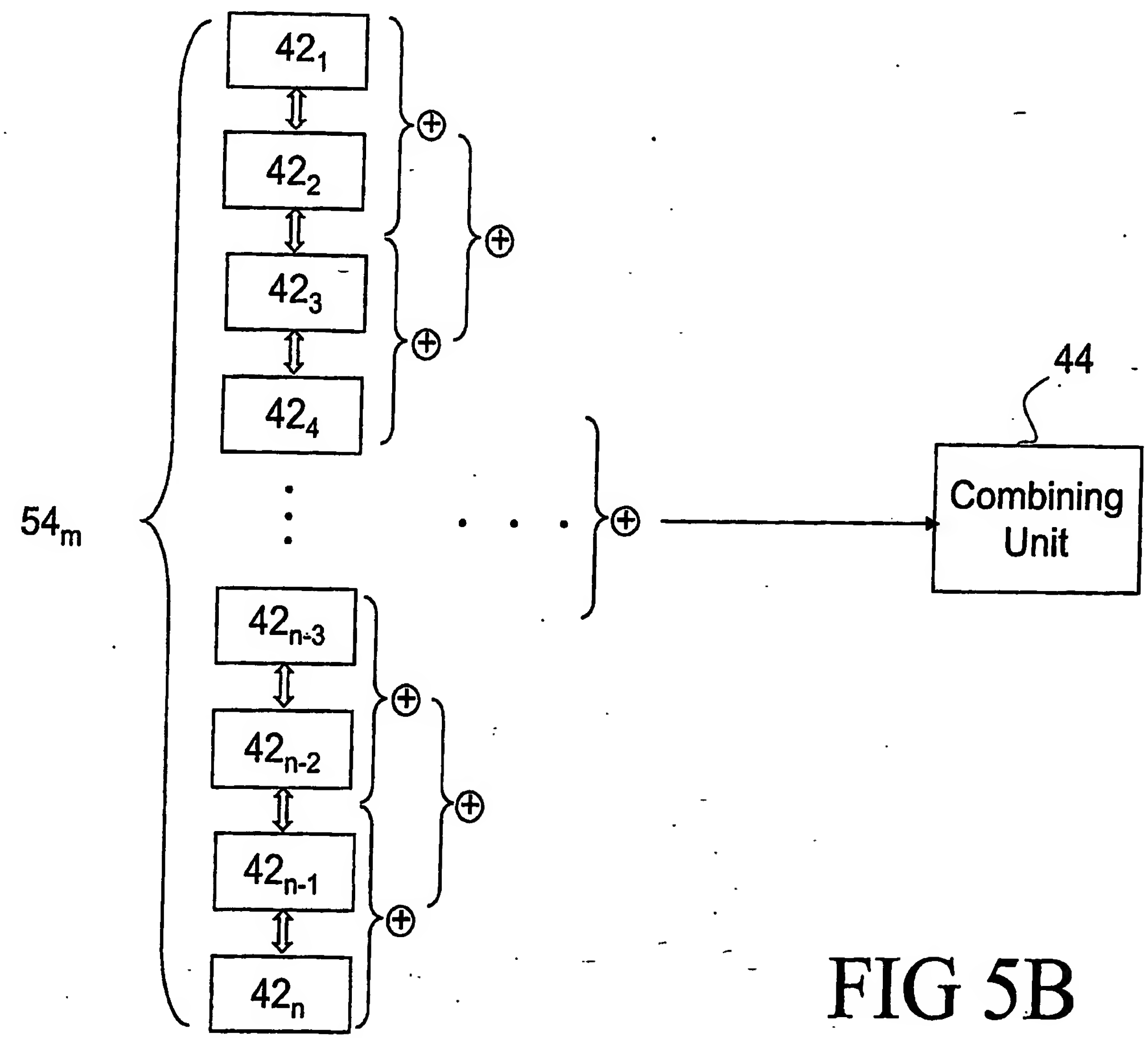


FIG 5B

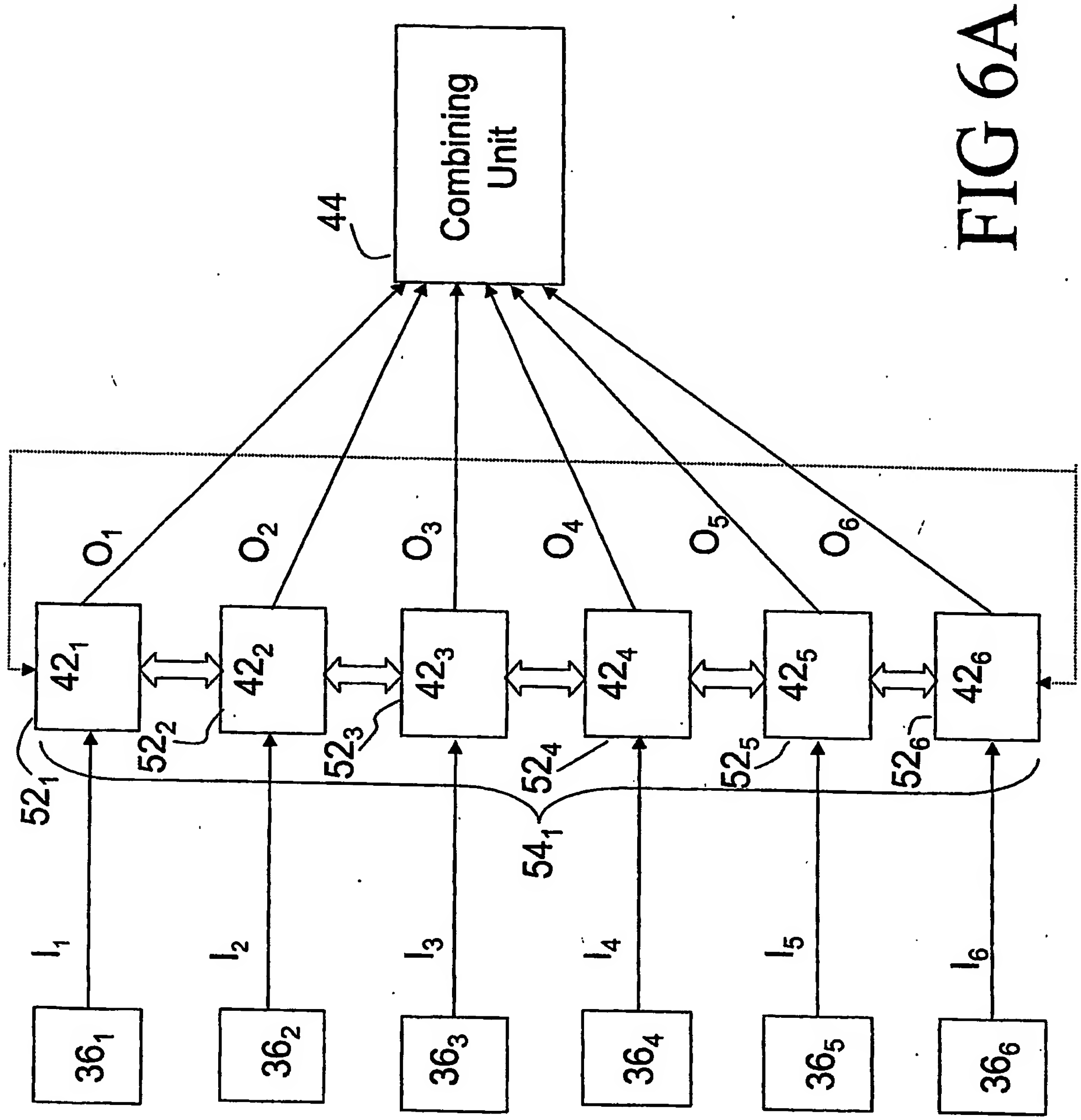
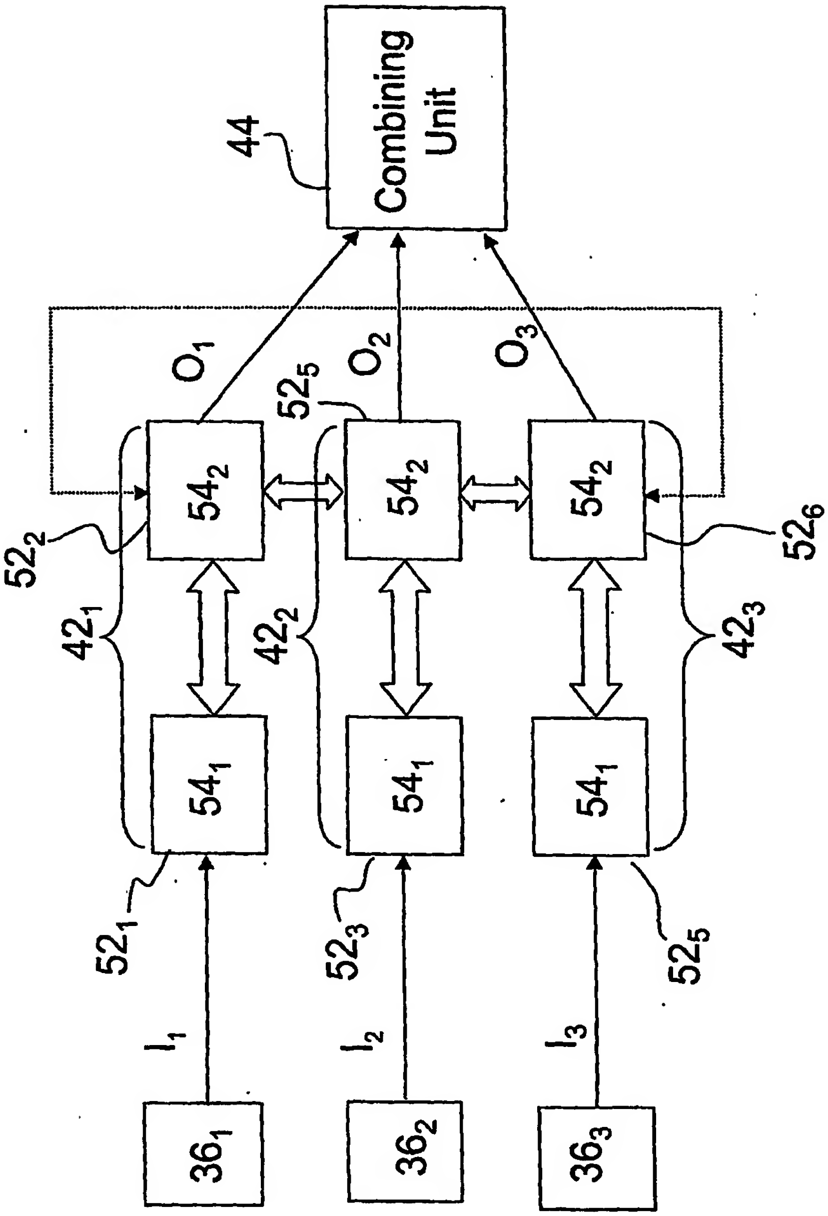

Combining Unit
44
O_1
O_2
O_3
O_4
O_5
O_6
42_1
42_2
42_3
42_4
42_5
42_6
52_1
52_2
52_3
52_4
52_5
52_6
54_1
I_1
I_2
I_3
I_4
I_5
I_6
36_1
36_2
36_3
36_4
36_5
36_6

FIG 6A



Combining Unit
44
O_1
O_2
O_3
52_5
54_2
54_2
54_2
52_2
52_6
42_1
42_2
42_3
54_1
54_1
54_1
52_1
52_3
52_5
I_1
I_2
I_3
36_1
36_2
36_3

FIG 6B

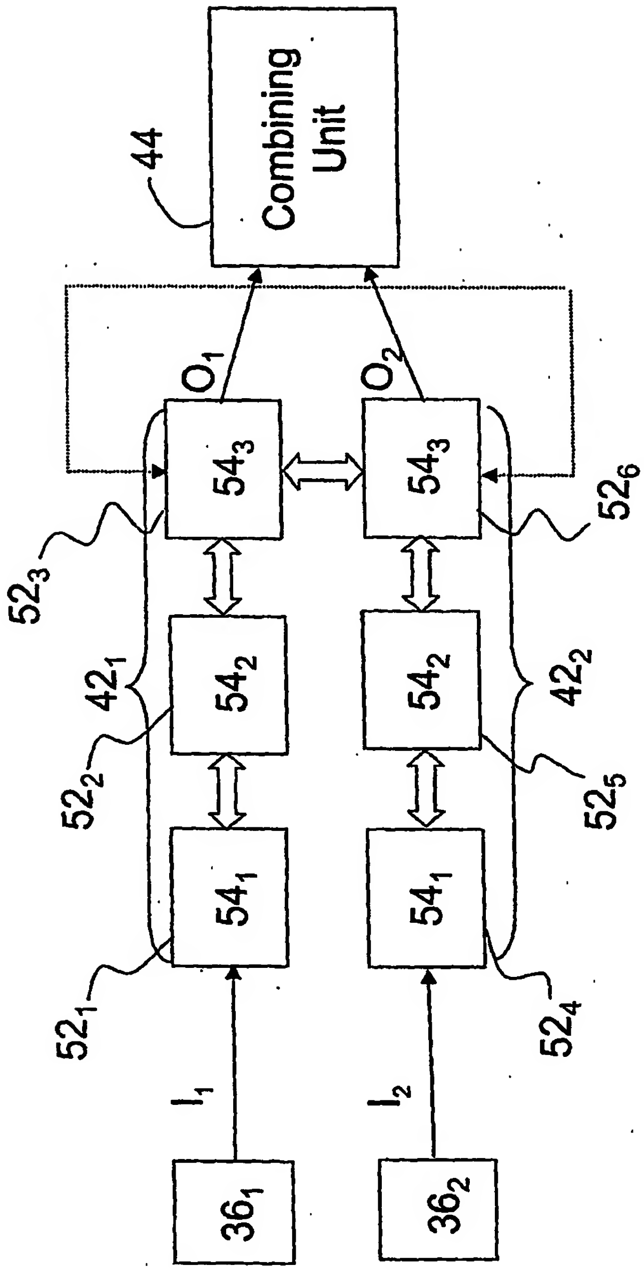
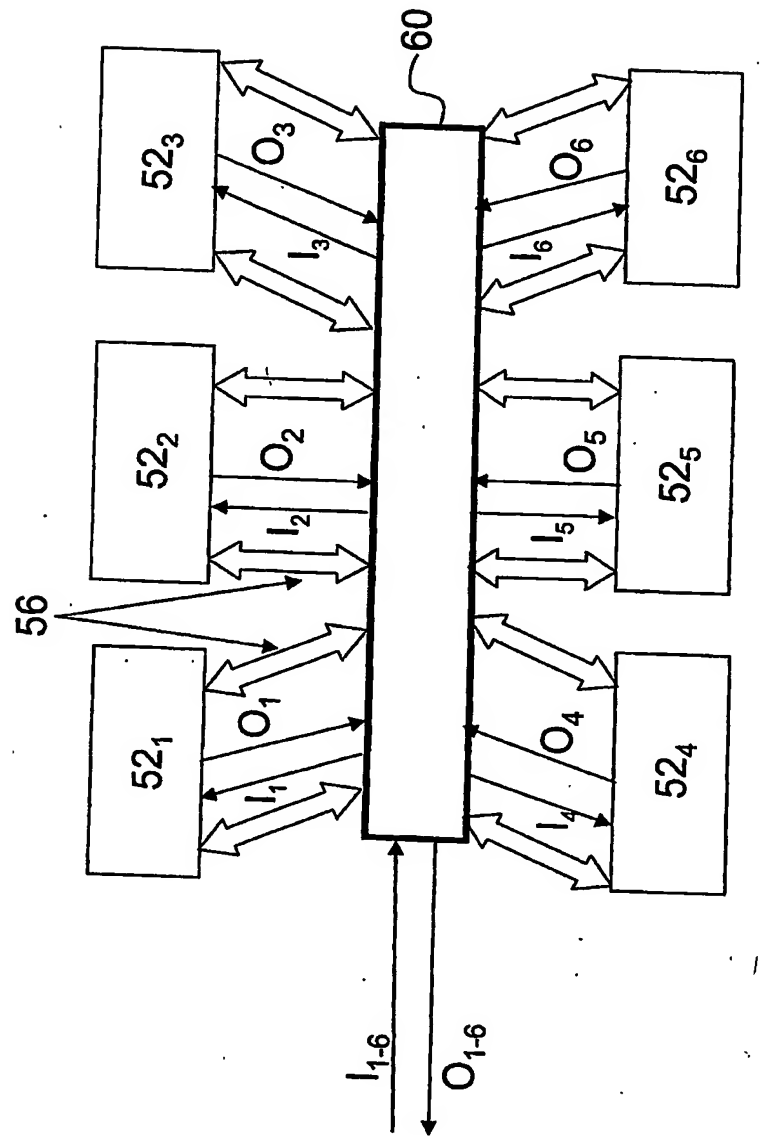

Combining Unit
44
O_1
O_2
54_3
54_3
54_2
54_2
54_1
54_1
52_1
52_2
52_3
52_4
52_5
52_6
42_1
42_2
I_1
I_2
36_1
36_2

FIG 6C



52₃
O₃
I₃
60
52₆
O₆
I₆
52₂
O₂
I₂
52₅
O₅
I₅
56
52₁
O₁
I₁
52₄
O₄
I₄
I₁₋₆
O₁₋₆

FIG 7A

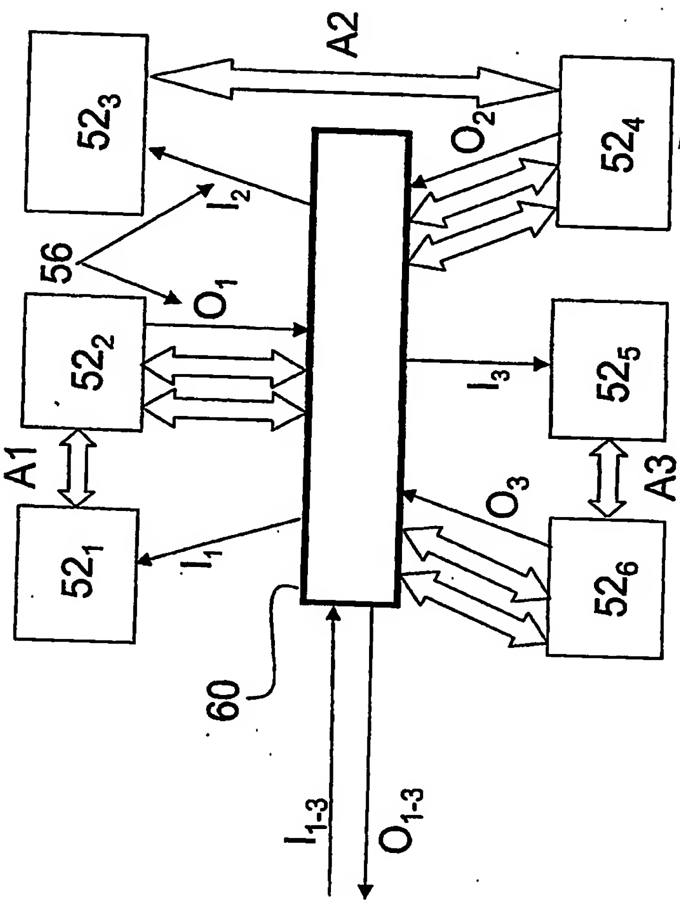


FIG 7B

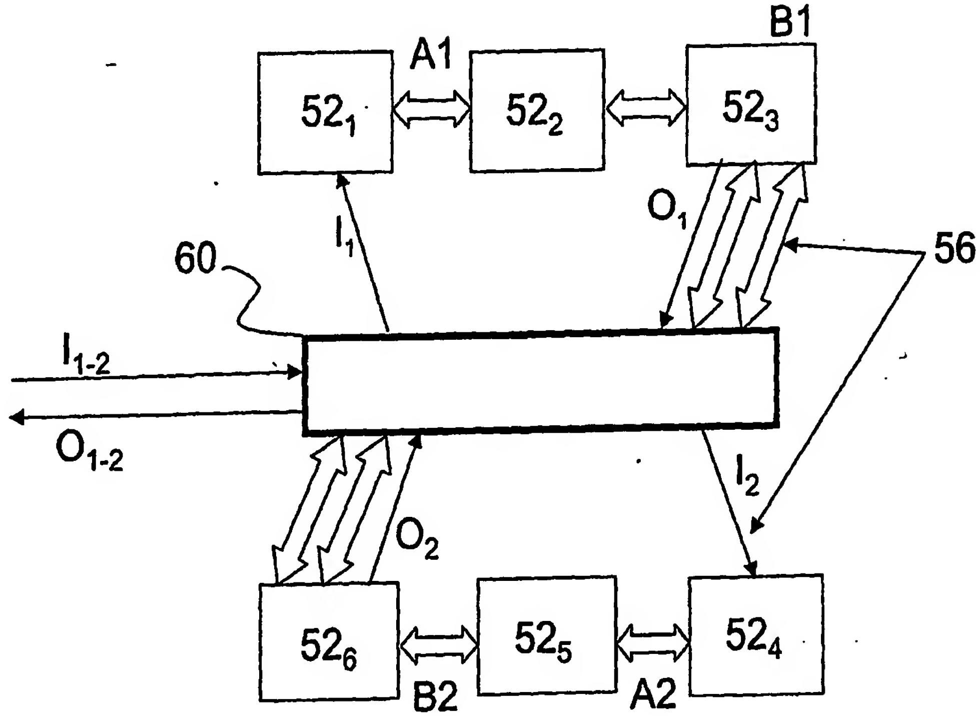
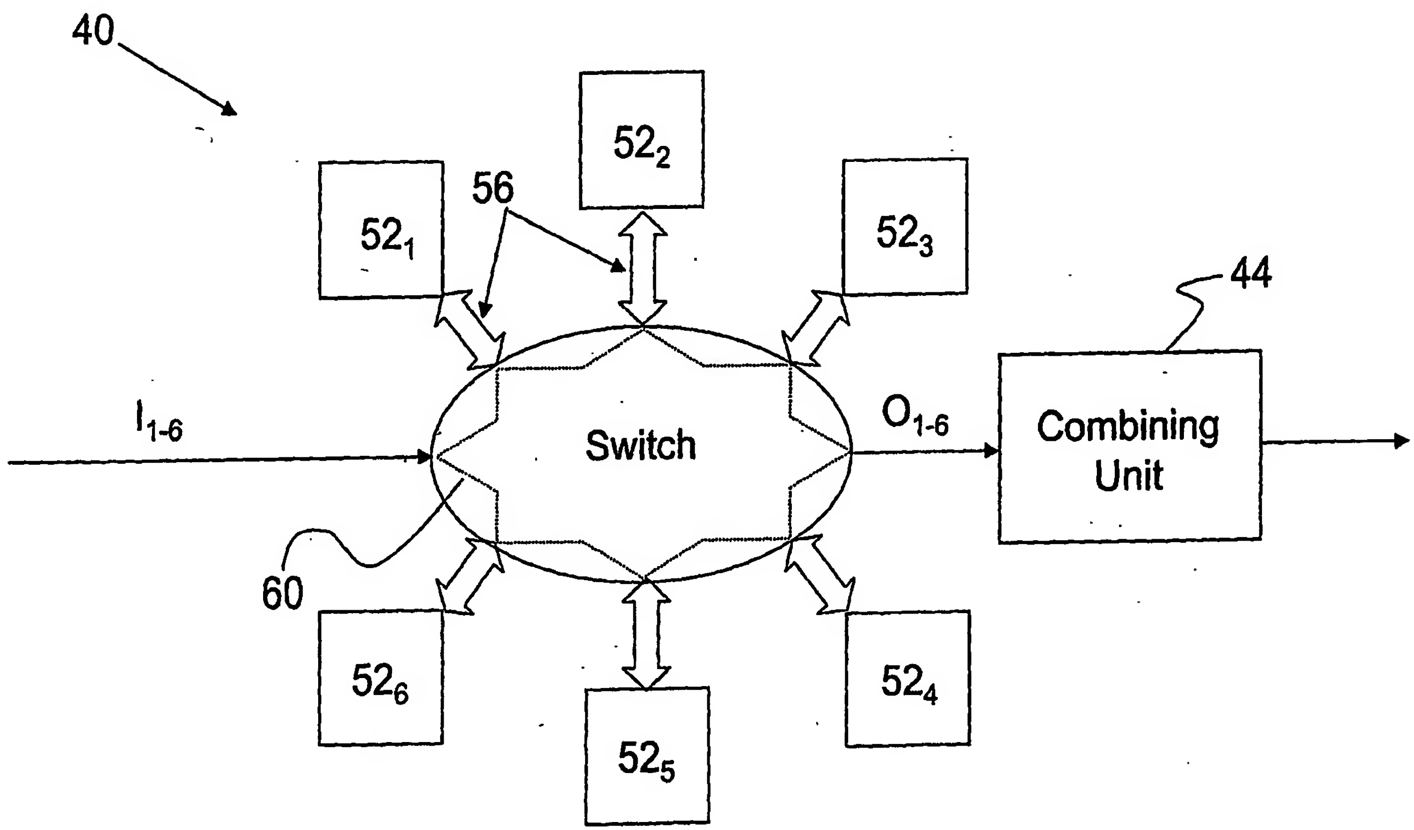


FIG 7C



40
56
52_1
52_2
52_3
44
I_{1-6}
Switch
O_{1-6}
Combining Unit
60
52_6
52_5
52_4

FIG 8